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SOME METHODS FOR APPROXIMATE PREDICTION OF SURFACE AREA OF FRUITS[1]

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INTRODUCTION

It is sometimes desirable to know the surface areas of apples that are to be used in investigations relating to spray coverage, spray-residue removal, respiration, or coloration. This paper presents the results of a study to determine whether satisfactory mathematical equations could be developed that would facilitate approximate predictions of exposed surfaces or surface areas of different varieties and kinds of fruits at different stages of growth or maturity.

MATERIAL AND PROCEDURE

During the fall of 1940 Johathan, Delicious, and McIntosh apples were obtained from orchards of the Michigan Agricultural Experiment Station for the purpose of determining surface areas of apples and making certain measurements that might be correlated with surface area. Jonathan apples were picked at random on September 5, September 20, and October 24; Delicious apples were harvested on September 14, September 28, and October 22; McIntosh apples were gathered when they reached maturity. Seventy-five apples were taken at each sampling period. Stayman and a second sample of McIntosh apples were bought in a store in Lansing, Mich., in December. Each apple was cut through the middle transversely as shown by a cross section in figure 1. Narrow strips of peel were then removed, pinned to a sheet of paper, and traced with a sharp pencil (fig. 1). The areas of each strip and each cross section were found by means of a planimeter, carefully manipulated by one person. The measurements made on Jonathan apple No. 2, harvested September 5, are shown in figure 1. Preliminary investigations with two samples, each of 100 apples from the 1939 crop, indicated that 75 fruits were enough to use for obtaining surface area with an accuracy of 5 percent of the mean.

After several trials it was found that the peeling should be cut into narrow strips (approximately three-fourths inch at the widest point) because when wide strips were used, the peelings wrinkled and were very difficult to trace accurately. The strips were between one-eighth and one-sixteenth inch thick. At this thickness the peeling will not curl at the edges when being traced and the pencil can move around the edges with little difficulty. Each strip was

[1] Received for publication May 4, 1942. Journal article No. 455 (n. s.) from the Michigan Agricultural Experiment Station.

fastened to the pad with several pins to prevent buckling; this held the peeling in position and flattened it on the paper. The pieces of peeling were more or less irregular at the ends because of the shapes of the basins and cavities of apples. A little care enabled the peeler to cut so as to remove the entire peeling to the bottom of the cavity or the basin.

Some slight errors were made in tracing and measuring areas with a planimeter, but careful work reduced these to very small amounts. The planimeter was read to 0.01 of a square inch. Any strip of peel, regardless of width, is convex or concave, depending on the side it is viewed from, and cannot therefore be made to lie completely on a flat surface. To secure an estimate of the amount of error caused by curvature, several pieces of tissue paper of different shapes (triangular, rectangular, and square) whose areas were known, were glued to various parts of the surface of an apple before it was peeled. These were cut from the apple with the peeling, pinned onto a sheet of paper, and traced. The areas of these tracings were found with the pla-

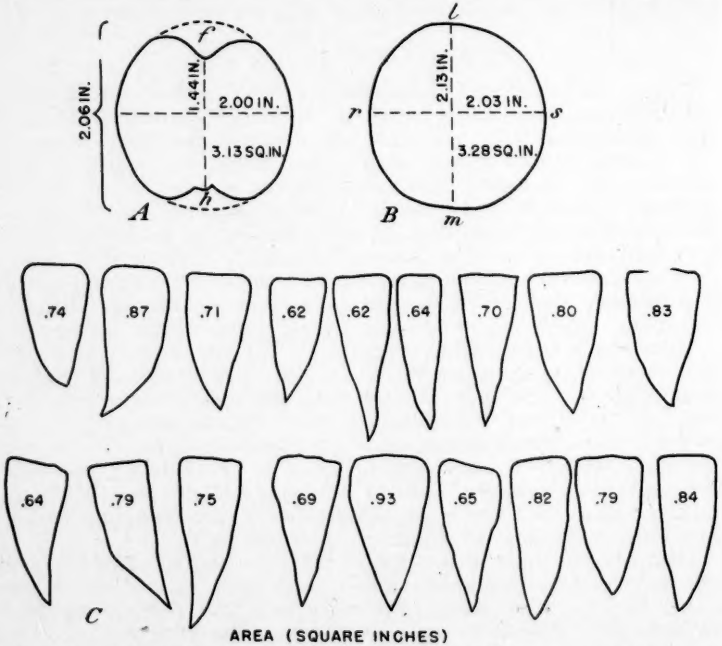

FIGURE 1.—Diagrams showing axial cross section (*A*), transverse cross section (*B*), and narrow strips of peel (*C*) removed from apple and pinned to a sheet of paper for tracing to determine the area with a planimeter. Measurements given are those of Jonathan apple No. 2, harvested September. 5.

nimeter. In several instances, the planimeter areas of these tracings were the same as the original areas of the tissue paper; in the others, the planimeter areas differed from the known areas by one or two points in the second decimal place. This would indicate that the

small strip-planimeter method will give good results, and that the sum of the areas of the peeling strips from an apple should be approxmately equal to the surface area of the apple.

Various methods have been employed for measuring the external surface of apples. Russell and Marshall [2] nailed one-half of an apple to a table, cheek facing the table and periphery of the cut surface marked with an indelible pencil, and then by tissue paper brought up around the half, estimated the surface area of half of the apple and then multiplied this by two to secure the entire surface of the apple. This method would appear to be difficult to use as the paper folds and wrinkles when brought up around the convex surface. Again, it is not easy to cut unsymmetrical apples into two equal parts.

SURFACE-AREA DETERMINATIONS FROM SURFACE OF ELLIPSOID [3]

The surface area of an ellipsoid with axes $a>b>c$, similar to the one shown in figure 2, is, according to Wilson, [4]

$$(1) \qquad 2\pi C^2+\frac{2\pi ab}{\sin\phi}\left[\frac{c^2}{a^2}F(\phi,k)+\frac{a^2-c^2}{a^2}E(\phi,k)\right], \text{ where } \cos\phi=\frac{c}{a},$$

$$k=\frac{b^2-c^2}{b^2\sin^2\phi}, F(\phi,k)=\int_0^{\phi}\frac{d\theta}{\sqrt{1-k^2\sin^2\theta}} \text{ and}$$

$$E(\phi,k)=\int_0^{\phi}\sqrt{1-k^2\sin^2\theta}\,d\theta.$$

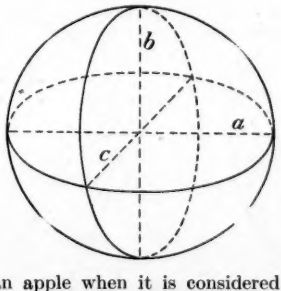

FIGURE 2.—Outline of an apple when it is considered as an ellipsoid with diameters, (a, b, c) equal to those of the McIntosh apple shown in figure 3, *C*.

To apply this formula to apples, it is necessary to show that apples may be considered as ellipsoids with some adjustments. If one were able to pull the peeling out from the stem cavity and from the basin, as is partly shown by dotted lines in figure 3, an object similar to an ellipsoid would result. The surface of the apple has not been changed, for the area of the skin in the cavity and the basin is the same after it is pulled out as before. With a little care one can draw the dotted lines so that the curvature at the points a and b, c, and d in figure 3

[2] RUSSELL, C. E., and MARSHALL, R. E. Unpublished data.

[3] The ellipsod formula was applied after trials with the formula for the surface area of a sphere, viz πd, where d represents the average of three diameters of an apple, failed to give good results.

[4] WILSON, E. B. ADVANCED CALCULUS. 1912. See. p. 516.

are the same for the dotted lines as for the contour of the apple. The length of the line *aeb* is not always equal to the dotted line *afb*, and the length of the line *cgd* is not always equal to the dotted line *chd*.

Figure 2 shows what the outline of an apple looks like if it is considered as an ellipsod with diameters equal to the diameters of the McIntosh apple shown in figure 3, *C*. The surface areas of ellipsoids, similar to the one shown in figure 2 constructed from measurements of the McIntosh apple in figure 3, *C*, were found by the formula

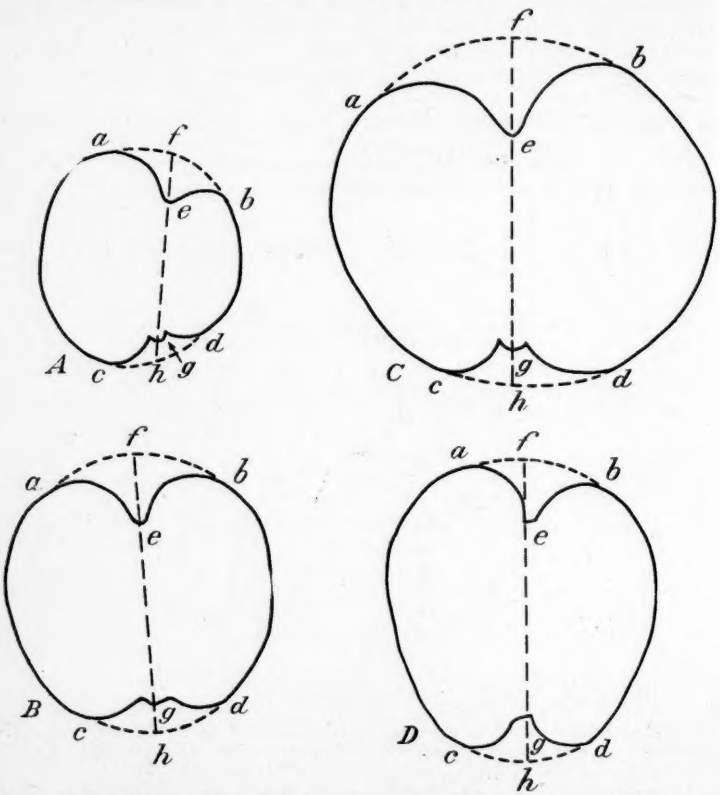

FIGURE 3.—Drawings showing axial cross sections of Jonathan apple No. 29 (*A*), Jonathan No. 28 (*B*), McIntosh (*C*), and Delicious (*D*). Dotted lines *afb* and *chd* show the approximate ellipsods that would result if the area of the skin in the stem cavity and basin were pulled out as shown.

given above. Of course an ellipsoid corresponding to each apple was not actually drawn as in figure 2. The surface area of an ellipsoid corresponding to each apple (by using dotted lines as shown above) was computed by the above formula and compared with the surface area found by the planimeter. Figure 3, *A* and *B*, shows the dotted lines for Jonathan apples Nos. 29 and 28, respectively.

The surface areas of these ellipsoids approximate closely the corresponding areas found with the planimeter.

A study of the differences in surface area obtained by the formula and those obtained by the planimeter showed that all were in absolute value less than 0.9 of a square inch and that only 6 were as large as 0.5 of a square inch. These facts, together with the plus and minus differences, show that formula 1 gives approximate values for the surface areas of Jonathan apples. The average error or the average difference is 0.03 square inch, and the standard deviation of these errors, which may be considered to be the standard error of estimate, is 0.35 square inch (table 1). The 43 positive and 30 negative differences indicate that formula 1 gives values a little too small since the error is considered to be the planimeter value minus the value obtained from formula 1. Formula 1 was applied to McIntosh, Delicious, and Stayman Winesap apples, with the results given in table 1.

Figure 3, *C* and *D*, shows how the rounding at the stem and blossom ends of McIntosh and Delicious was made by the dotted lines. An apple is not an ellipsoid (a section through the axis does not cut the apple into two equal parts), but the surface area computed from the ellipsoid described is nearly equal to that obtained from the planimeter measurements (table 1). The errors pertaining to Delicious apples are larger than those pertaining to Jonathan, McIntosh, or Stayman Winesap; those for Jonathan (first harvest) being on the average the smallest. No doubt the points or crowns and accompanying corrugations at the blossom end of the Delicious fruits gave rise to errors, as did also the broad flattened shapes of the McIntosh fruits.

TABLE 1.—*Averages of the differences in surface area, in square inches, of different varieties of apples determined by formula (1) and planimeter readings*

Variety	Harvested—	Mean difference	σ	Maximum error	Percent less than 1 square inch in error
Jonathan	Sept. 5	0.03	0.35	0.87	100
Delicious	Mature	.98	1.15	2.09	51
McIntosh:					
First sample	do	.20	.63	1.20	93
Second sample	do	−.11	.63	1.76	85
Stayman Winesap	do	.68	.98	2.08	68

Since formula (1) involves two incomplete elliptic integrals, cosines of angles and radicals, it is very difficult to use. An expert computer requires about 20 minutes to calculate the surface area of one apple with this complicated formula. It is therefore not practical to employ, although it does give very good results. Other less complex formulas were developed and compared with formula (1).

SURFACE-AREA PREDICTIONS FROM TRANSVERSE CROSS SECTION

The areas of the transverse cross sections shown in figure 1 and the surface areas obtained from the planimeter are plotted in figure 4 for Jonathan and McIntosh apples at maturity. This graph and similar ones for the other varieties suggest a linear relation between the areas of the transverse cross sections and surfaces areas. The predicting

straight lines are drawn in the chart together with the bands of "normality." The width of both bands is two times the size of the standard error of estimate. This band shows on the average the in-

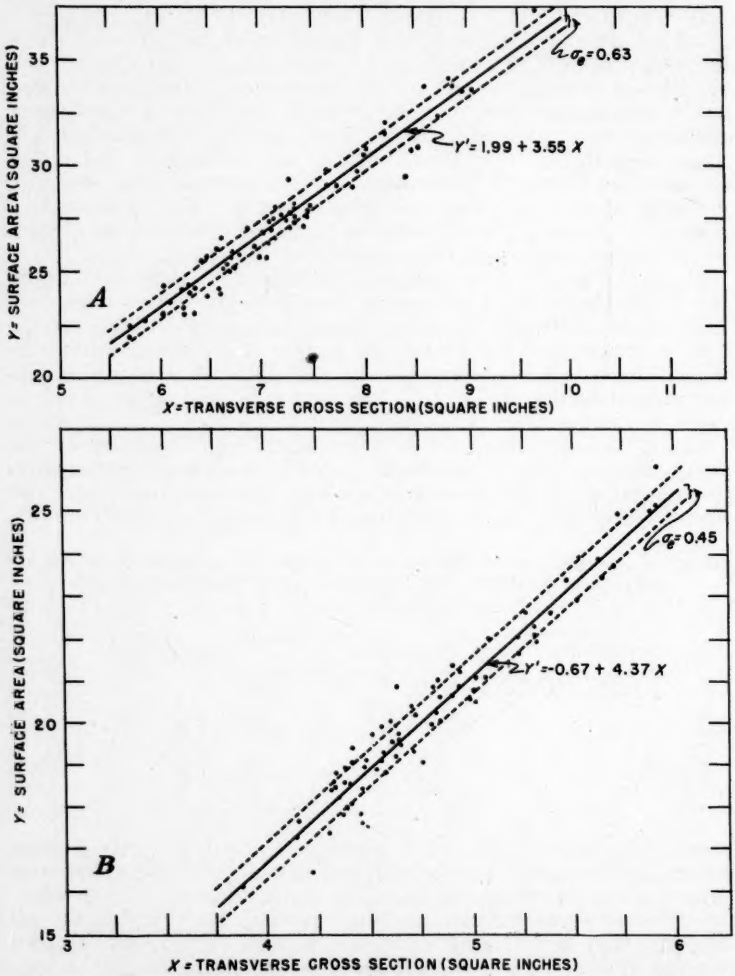

FIGURE 4.—Areas of the transverse cross sections shown in figure 1 and the surface areas obtained from planimeter readings plotted for McIntosh applies (*A*) and Jonathan apples (*B*) at maturity.

terval in which 68.2 percent of the observed values of surface areas will fall if the predicting equation is used for estimating the surface area. In this chart the scatter diagrams fall along the straight lines,

indicating a rather definite association between these two variables. The size of the standard error of estimate reveals the magnitude of the average error when the predicting equation is used. Table 2 contains the predicting equations for the varieties for the different harvesting dates, together with the standard errors of estimate. These equations were found when $y=a+bx$ and $y=cx$ were used as the linear relation between planimeter surface area and area of transverse cross section. If the apples were perfect spheres, the surface area would be equal to $y'=4x$. The constant c is in the neighborhood of 4.

TABLE 2.—*Equations for predicting surface area from the area of transverse cross section* [1] *of apples of different varieties harvested at different times*

Variety	Harvested—	Mean surface area	Equation	σ
		Square inches		*Square inches*
Jonathan	Sept. 5	13.17	$y'=-0.05+4.11x$	0.51
			$y'=4.09x$	.56
	Sept. 20	17.10	$y'=.23+4.13x$	.54
			$y'=4.19x$	.55
	Oct. 24	20.31	$y'=-.67+4.37x$	.45
			$y'=4.24x$	.46
Delicious	Sept. 14	17.24	$y'=-.34+4.07x$	.56
			$y'=3.99x$	.56
	Sept. 28	17.04	$y'=.40+3.97x$	.82
			$y'=4.06x$	.83
	Oct. 22	21.72	$y'=2.02+3.83x$	.88
			$y'=4.22x$	.92
McIntosh	Mature	27.67	$y'=.38+3.77x$	.77
			$y'=3.82x$	.78
	do	22.62	$y'=1.99+3.55x$	.63
			$y'=3.69x$	.66
Stayman Winesap	do	24.35	$y'=.84+3.92x$	1.12
			$y'=4.06x$	1.13

[1] x=area of transverse cross section; y'=predicted value.

The sizes of the standard errors of estimates show that one can predict the surface area of apples from the equation $y'=cx$ about as well as from the equation with a constant in it, $y'=a+bx$. This means that the surface area is equal to a constant factor times the area of the transverse cross section. The errors on the average in table 2 are larger than the errors in table 1, showing that formula (1) is the better, except in the case of Delicious apples.

SURFACE-AREA PREDICTIONS FROM LONGITUDINAL SECTION

When surface areas were predicted from the areas of the longitudinal or axial cross sections shown in figure 1, the results recorded in table 3 were obtained. If the standard errors of estimate in table 2 and table 3 are compared, it will be seen that those in table 3 are a little larger, except in the case of Stayman Winesap. This shows that the areas from transverse cross sections result in scatter diagrams that fit the lines for predicting surface areas a little better than the areas from longitudinal cross sections; the differences are not very large.

TABLE 3.—*Equations for predicting surface area from the area of axial or longitudinal cross section*[1] *of apples of different varieties harvested at different times*

Variety	Harvested—	Equation	σ_e
			Square inches
Jonathan	Sept. 5	$y' = 0.62 + 4.33s$	0.62
	Sept. 20	$y' = 4.54s$	.62
		$y' = .11 + 4.61s$	.60
	Oct. 24	$y' = 4.64s$	.60
		$y' = .72 + 4.52s$	.68
		$y' = 4.69s$	.69
Delicious	Sept. 14	$y' = .81 + 4.13s$	.82
	Sept. 28	$y' = 4.33s$	.82
		$y' = .23 + 4.32s$	.78
	Oct. 22	$y' = 4.38s$	.78
		$y' = 2.54 + 4.05s$	1.01
		$y' = 4.57s$	1.06
McIntosh	Mature	$y' = .05 + 4.84s$	1.36
		$y' = 4.85s$	1.36
	do	$y' = 3.66 + 3.88s$	.88
		$y' = 4.62s$	.96
Stayman Winesap	do	$y' = 2.20 + 4.30s$	1.01
		$y' = 4.72s$	1.07

[1] s = longitudinal cross section.

SURFACE-AREA PREDICTIONS FROM DIAMETER MEASUREMENT

Since the areas of cross sections usually are not easy to calculate, equations for estimating surface areas were obtained from the largest or transverse diameters and then from the longitudinal or vertical diameters (distance from the bottom of the cavity to the bottom of the basin). These predicting equations together with their standard errors of estimate are given in tables 4 and 5.

TABLE 4.—*Equations for predicting surface area from the transverse diameter*[1] *of apples of different varieties harvested at different times*

Variety	Harvested—	Equation	σ_e
			Square inches
Jonathan	Sept. 5	$y' = -13.09 + 12.65t$	0.64
		$y' = 6.42t$	1.21
	Sept. 20	$y' = -16.45 + 14.48t$	.60
		$y' = 7.41t$	1.21
	Oct. 24	$y' = -18.22 + 15.40t$	.68
		$y' = 8.14t$	1.16
Delicious	Sept. 14	$y' = -17.21 + 14.51t$	.63
		$y' = 7.29t$	1.31
	Sept. 28	$y' = -15.70 + 13.94t$	.73
		$y' = 7.29t$	1.39
	Oct. 22	$y' = -19.18 + 15.77t$	.97
		$y' = 8.41t$	1.56
McIntosh	Mature	$y' = -25.94 + 17.39t$	.93
		$y' = 9.01t$	1.95
	do	$y' = -16.86 + 14.24t$	.81
		$y' = 8.18t$	1.20
Stayman Winesap	do	$y' = -21.43 + 16.38t$	1.07
		$y' = 8.75t$	1.94

[1] t = transverse diameter.

TABLE 5.—*Equations for predicting surface area from axial or longitudinal diameters* [1] *of apples of different varieties harvested at different times*

Variety	Harvested—	Equation	σ_s
			Square inches
Jonathan	Sept. 5	$y' = 0.03 + 9.83l$	1.77
		$y' = 9.85l$	1.77
	Sept. 20	$y' = 2.73 + 10.20l$	1.83
		$y' = 12.13l$	1.85
	Oct. 24	$y' = 6.49 + 9.36l$	1.77
		$y' = 14.65l$	1.89
Delicious	Sept. 14	$y' = -3.58 + 12.54l$	1.71
		$y' = 7.21l$	1.74
	Sept. 28	$y' = -3.82 + 12.84l$	2.04
		$y' = 10.51l$	2.06
	Oct. 22	$y' = 8.67 + 8.15l$	2.38
		$y' = 13.69l$	2.58
McIntosh	Mature	$y' = -1.50 + 16.56l$	3.17
		$y' = 15.72l$	3.18
	do	$y' = 8.14 + 10.25l$	1.92
		$y' = 15.97l$	2.03
Stayman Winesap	do	$y' = -5.33 + 19.65l$	2.86
		$y' = 16.13l$	2.88

[1] l=longitudinal diameter.

Values of the standard errors of estimate in tables 4 and 5 show that the transverse diameter is better to use for predicting surface area than the longitudinal or axial diameter. This is as it should be since the longitudinal diameter does not reveal the bulges or ridges of angular fruits. By comparing values in tables 2, 3, and 4, it is observed that predicting from the transverse diameter in most cases gives results about as good as predicting from areas of cross sections. The standard errors of estimate are recorded in table 6 for comparison. Figure 5 shows the relation between surface areas and transverse diameter measurements. The dots in these charts fall very close to the straight lines; the bands of "normality" are rather small for each set of data and for each variety. Measurements of the transverse diameters can be made easily and quickly with calipers on uncut apples.

TABLE 6.—*Standard errors of estimate obtained by predicting surface areas from areas of cross sections and transverse diameters* [1] *of apples of different varieties harvested at different times.*

Variety	Harvested	Measurement	σ_s
			Square inch
Jonathan	Sept. 5	Transverse cross section	0.51
		Axial cross section	.62
		Transverse diameter	.64
	20	Transverse cross section	.54
		Axial cross section	.60
		Transverse diameter	.60
	Oct. 24	Transverse cross section	.45
		Axial cross section	.68
		Transverse diameter	.68
Delicious	Sept. 14	Transverse cross section	.56
		Axial cross section	.82
		Transverse diameter	.63
	28	Transverse cross section	.82
		Axial cross section	.78
		Transverse diameter	.73
	Oct. 22	Transverse cross section	.88
		Axial cross section	1.01
		Transverse diameter	.97
McIntosh	Mature	Transverse cross section	.77
		Axial cross section	1.36
		Transverse diameter	.93
	do	Transverse cross section	.63
		Axial cross section	.88
		Transverse diameter	.81
Stayman Winesap	do	Transverse cross section	1.12
		Axial cross section	1.01
		Transverse diameter	1.07

[1] $y'=a+b$ (x, s, or t)

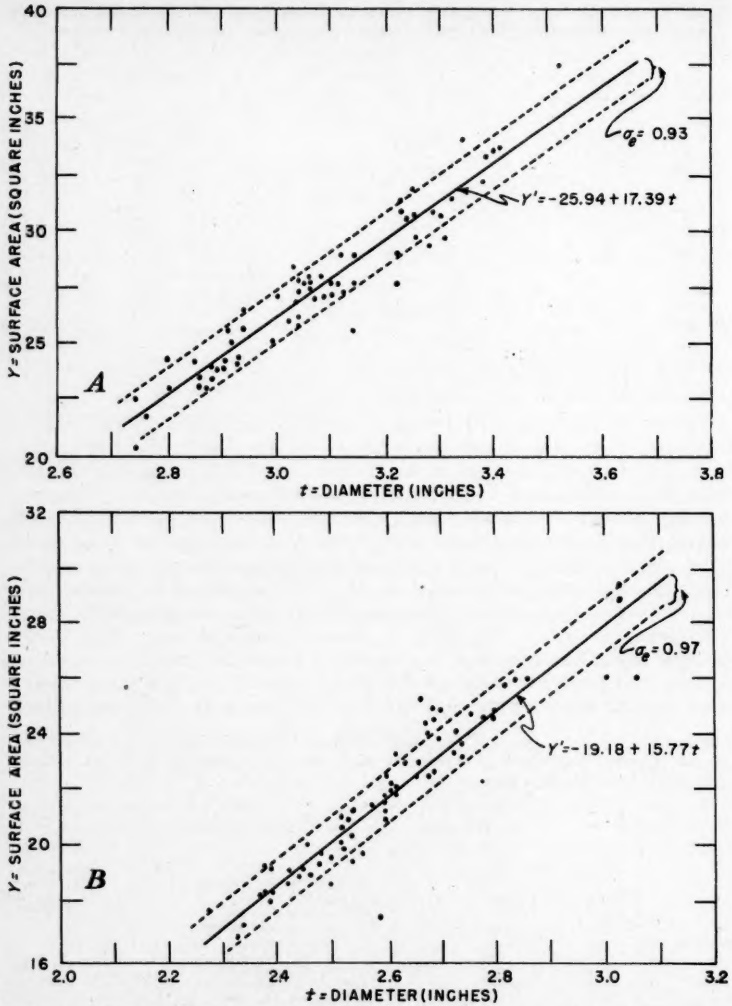

FIGURE 5.—The relation between surface area and transverse diameter measurements of McIntosh apples (*A*) and Delicious apples (*B*).

SURFACE-AREA PREDICTIONS FROM WEIGHTS

The last pickings of Jonathan and Delicious apples in 1940 were weighed, and the weights were plotted against corresponding surface areas of the fruits. A very definite linear relation between weight and surface area resulted (table 7). Since very good results were obtained from weights of the two varieties, 75 McIntosh apples and 75 Stayman Winesap apples were secured from local stores for further study.

TABLE 7.—*Equations for predicting surface areas from weight* [1] *of apples of different varieties, 1940 and 1941*

Variety and year grown	Mean surface area	Equation	σ_e	$100\frac{\sigma_e}{M_y}$ [2]	$100\frac{\sigma_e}{M_y}$ [3]	r_{yw}
	Square inches		*Square inch*	*Percent*	*Percent*	
Jonathan:						
Mature, 1940	20.31	$y'=6.437+0.136w$	0.48	2.31	3.16	0.97
Picked Sept. 11, 1941	16.94	$y'=5.194+.147w$	.58	3.42	3.79	.96
Picked Sept. 23, 1941	18.22	$y'=5.307+.146w$	.52	2.85	2.96	.96
Delicious, 1940	21.72	$y'=6.623+.129w$	.46	2.12	2.14	.99
McIntosh, 1940	22.62	$y'=7.122+.129w$	.40	1.77	2.25	.98
Stayman, Winesap, 1940	24.35	$y'=8.420+.112w$	.62	2.55	4.68	.99
Wagener, 1941	25.17	$y'=7.085+.121w$	.58	2.30	4.18	.98
Gravenstein, 1941	25.49	$y'=8.241+.116w$	.52	2.04	3.78	.96
Chenango, 1941	19.29	$y'=6.906+.128w$	.58	3.01	3.52	.94
Grimes Golden, 1941	17.25	$y'=5.889+.125w$	.70	4.06	7.64	.92
Average		$y'=6.722+.129w$				

[1] w = weight.
[2] "Coefficient of variability."
[3] Obtained from average equation.

In view of the excellent results obtained for predicting surface area from weight with four varieties of the 1940 crop, it seemed advisable to enlarge this phase of the study the following year with additional varieties of various shapes. Weight and surface area measurements were therefore made during the fall of 1941 on the following varieties: Wagener, Gravenstein, Chenango, Grimes Golden, and Jonathan. In the case of Jonathan, one picking was made about 3 weeks before the commercial picking date for that variety, and a second picking was made approximately 10 days before full maturity. These, together with the Jonathans picked when mature in 1940, provided three stages of maturity for this variety. Table 7 shows the predicting equations, standard errors of estimate, "coefficients of variation," and correlation coefficients for the several varieties grown in 1940 and 1941.

The standard errors of estimate indicate that the predicting equations give splendid results for estimating surface areas from weights. The largest error is 0.70 square inch. The "coefficient of variability" $\left(100\frac{\sigma_e}{My}\right)$ is the ratio of the standard error of estimate to the mean, the ratios being expressed as percentages. In every case, these values are less than 4.1 percent; this again shows the accuracy of the predicting equations. The large values of the correlation coefficients, shown in the last column of table 7 (r_{yw}), also indicate excellent results (see figs. 6 and 7).

A study of table 7 shows that the slopes of the equations are about the same; the difference between the largest slope, 0.147, and the smallest slope, 0.112, is only 0.035. There is not a great deal of difference between the values of the constant terms in these equations. These facts suggest that one predicting equation might be used for all varieties for predicting surface area from weight. The equation, obtained by averaging the equations for the varieties listed in table 7, was found to be $y'=6.722+0.129W$.

The predicted value for each apple was determined by this equation. The deviations of the observed surface areas from predicted surface areas were then found for each fruit. The "standard errors of estimate" were obtained for each variety by finding the square root of the average of the squares of the deviations from this average equation; these were compared with the former standard errors of estimate (table 7, column 4) and also with the means. In only one case did the "coefficient of variability" exceed 5 percent or in only one case did the new standard errors of estimate exceed 5 per-

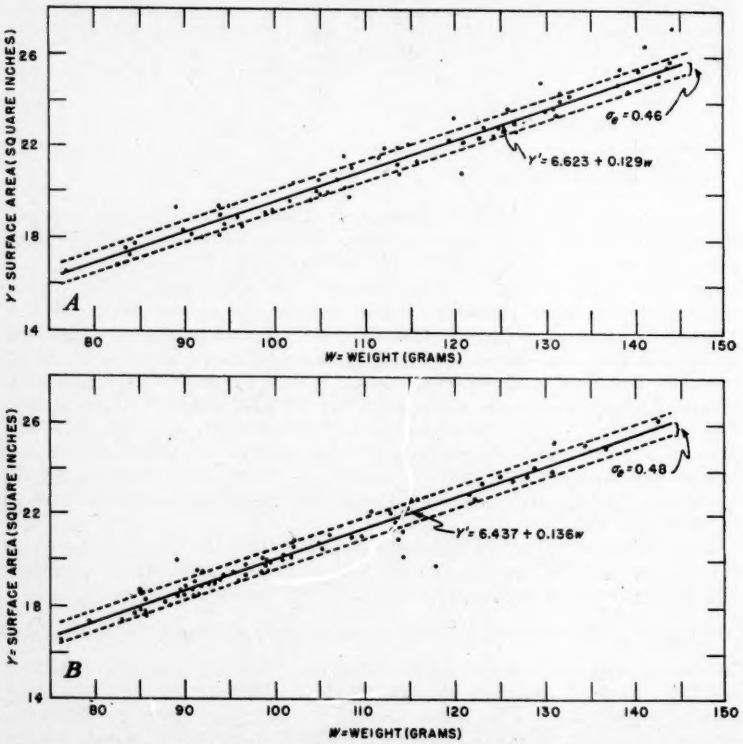

FIGURE 6.—The relation between weight and surface area of Delicious apples (*A*) and of Jonathan apples (*B*).

cent of the respective mean; this was for the variety Grimes Golden. The percentage in this case was 7.64 (table 7). These facts suggest that one relationship between weights and surface areas might be used for approximating surface areas from weights for any variety of apple.

It is interesting to note that the predicting equations for Jonathans picked on September 11 and September 23, 1941, are almost identical, which suggests that during the latter part of the growing season, the relation beween weight and surface area remains the same.

The question arises as to whether weights are better for predicting surface areas of apples than transverse sections. On examining the errors of estimate in tables 2 and 7, it is seen that for Jonathan apples one is as good as the other, but for Delicious and Stayman Winesap weight is better. A test to determine whether or not the weight is better than the transverse-section measurement for estimating surface

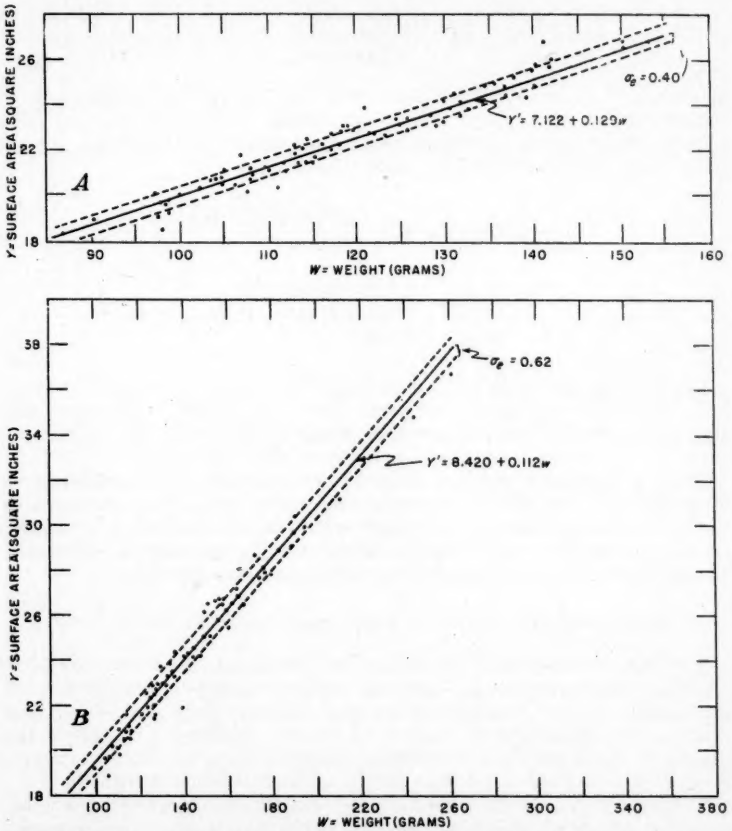

FIGURE 7.—The relation between weight and sufrace area of McIntosh apples (*A*) and of Stayman Winesap apples (*B*).

area for the McIntosh variety follows. The error of estimate when weights are used is 0.40; the error of estimate when transverse section is used 0.63. Are these significantly different? To obtain information on this point Hotelling's [5] test was employed. This test is given in detail because it is a very useful one and can be employed in many instances for determining which of two variables is better for predict-

[5] HOTELLING, H. THE SELECTION OF VARIATES FOR USE IN PREDICTION WITH SOME COMMENTS ON THE GENERAL PROBLEM OF NUISANCE PARAMETERS. Ann. Math. Statis. 11: 271–283. 1940.

ing a third variable. Applications of this test are given elsewhere.[6] The test is made by finding the following quantities:

$$t=(r_{yw}-r_{yx})\sqrt{\frac{(n-3)(1+r_{xw})}{2D}}$$

where

$$D=\begin{vmatrix}1 & r_{yx} & r_{yw}\\ r_{yx} & 1 & r_{xw}\\ r_{yw} & r_{xw} & 1\end{vmatrix},$$

where r_{yx}, r_{yw}, and r_{xw} are respectively the correlation coefficients between surface area y and transverse section x, between surface area and the weight w, and between transverse section and weight. In the case under consideration, the above quantities are:

$$t=(0.983-0.959)\sqrt{\frac{72(1.968)=4.408,}{0.0042}}$$

$$D=\begin{vmatrix}1 & 0.959 & 0.983\\ 0.959 & 1 & 0.968\\ 0.983 & 0.968 & 1\end{vmatrix}=0.0021.$$

On entering a t table at 72 degrees of freedom, it is found that there is a significant difference between these correlation coefficients and also the errors of estimate, or that weights are better for predicting surface areas than transverse sections of McIntosh apples.

Since weight and volume of fruits are closely related, surface-area formulas could be developed for predicting or estimating surface area from volume measurements. Such would be workable only with detached fruits, and since apples float, weight measurements would appear to be more practical than volume measurements.

RELATION OF SURFACE AREA AND WEIGHT OF PEARS

Surface area and weight measurements of Anjou, Bosc, and Bartlett pears were made in 1941 by the same methods that were employed with the apples. These varieties were used because they represent three distinct and characteristic shapes of pears. Hedrick[7] describes the shapes of these varieties as follows: Anjou, oblong-obovate-pyriform; Bosc, acute-obovate-pyriform; Bartlett, oblong-obtuse-pyriform.

Table 8 contains equations for predicting surface area from weight, standard errors of estimate, "coefficients of variability", and correlation coefficients for the pears. This table shows clearly that the surface areas for these varieties can be estimated very accurately from weights of fruits. The three predicting equations differ slightly from each other, which suggests that one equation might be used for all varieties. The equation resulting from the average of these three

[6] BATEN, W. D. HOW TO DETERMINE WHICH OF TWO VARIABLES IS BETTER FOR PREDICTING A THIRD VARIABLE. Amer. Soc. of Agron. Jour. 33: 695-699, illus. 1941.

[7] HEDRICK, U. P. CYCLOPEDIA OF HARDY FRUITS. 370 pp., illus. New York. 1922.

equations was used to estimate the surface area of each pear. This equation is $y'=7.4904+0.0995w$. Differences were found between the observed values and the predicted values from this average equation. The square root of the average of the squares of the differences was found for each variety and compared with the standard errors of estimate listed in table 8. There was very little difference between these values as is seen by examining the fourth and fifth columns in table 8. Of course, the individual equations found by the method of least squares should lead to the smaller errors of estimate. The results given above show that the equation found by taking the average of the equations can be used for estimating surface areas from weights rather accurately.

TABLE 8.—*Equations for predicting surface areas from weights of pears*

Variety	Mean surface area	Equation	σ_e	"σ_e" from average equation	$100\left(\frac{\sigma_e}{\bar{M}y}\right)$	r_{yw}
	Square inches		*Square inch*	*Square inch*	*Percent*	
Anjou	23.05	$y'=7.4004+0.0973w$	0.597	0.777	2.59	0.98
Bosc	22.18	$y'=7.4876+.1008w$	.795	.801	3.58	.96
Bartlett	22.54	$y'=7.5833+.1005w$	.693	.729	3.07	.97
Average		$y'=7.4904+.0995w$				

RELATION OF SURFACE AREA AND WEIGHT OF PLUMS

Two fully matured varieties of plums having somewhat different shapes were studied in 1941. The Monarch variety is a round-oval plum, and the Pond is ovate to obovate in shape. Seventy-five fruits of each were weighed and the surface areas determined, the same methods being used that were employed with the apples and pears.

Table 9 shows the predicting equations, the standard errors of estimate, "coefficients of variability," and correlation coefficients. Although only two varieties were studied, it appears that the equation found by averaging the equations for the two varieties may be used with a fair degree of accuracy for determining the surface areas of varieties of plums.

DISCUSSION

Several different kinds of measurements of apple fruits grown in 1940 were made in an effort to develop an equation that might be used with a fair degree of accuracy to predict surface areas of these fruits. Each of these measurements gave straight line relationships with surface area, thus permitting use of the equation $y=a+bx$ in predicting approximate surface areas. The fruit measurement that resulted in the smallest average and the most uniform standard errors when plotted against actual surface-area measurements was found to be weight of apples.

TABLE 9.—*Equations for predicting surface areas from weights of plums*

Variety	Mean surface area	Equation	σ_s	"σ_s" from average equation	$100\left(\frac{\sigma_s}{My}\right)$	r_{yw}
	Square inches		*Square inch*	*Square inch*	*Percent*	
Pond	7.01	$y'=2.491+0.138w$	0.220	0.227	3.14	0.95
Monarch	5.43	$y'=1.876+.159w$	.147	.181	2.71	.94
Average		$y'=2.184+.149w$				

Inasmuch as weight determinations of harvested or detached apples is the most practical measurement to make of the several that were studied, it was deemed advisable to enlarge upon this phase of the study with apples in 1941 and to include some varieties of pears and plums having various shapes. In view of the fact that 15 sets of determinations with these fruits resulted in only 1 case (the Grimes Golden variety of apple) where the standard error of estimate exceeded 5 percent of the mean, the authors recommend the predicting equations involving weights of fruits where harvested, or detached fruits can be used.

Furthermore, the data indicate that it is possible to use one equation for several varieties of the same kind of fruit with at least a fair degree of accuracy. The average equation for the varieties of apples studied was $y'=6.72+0.13w$. When this was used as the predicting equation for the individual apples of 10 sets of weight measurements made in 1940 and 1941, the standard error of estimate exceeded 5 percent of the mean only in the case of the Grimes Golden variety. Similar results were obtained with average equations for pears and plums.

If it is necessary to determine approximate surface areas for apples that are attached to the tree, it is suggested that the predicting equation for surface area be based on transverse diameter measurements, which can be made readily with calipers.

Predicting equations for surface areas should be based on straight-line trends or relationships for 75 fruits that represent the ranges of shapes and sizes in approximately the proportions that actually occur on the plant or the fruits being studied. When the sample of fruits used in this study contained much fewer than 75 specimens, the standard error of estimate usually exceeded 5 percent of the mean. On the other hand, there appears to be no advantage in using a larger sample if the fruits selected are truly representative of those on the plant or in the lot to be measured.

The fruits used in this study were mature or within 3 to 4 weeks of full maturity. The predicting equations for surface areas seem to be entirely satisfactory for use within the range of growth period or degree of maturity studied, and they apparently may be used with fruits much farther from full maturity.

In view of the fact that the varieties of apples, pears, and plums used in this study afforded a wide range of sizes and shapes, the

authors believe that transverse diameter or weight measurements may be used to predict surface areas of fruits throughout the growing season, provided a representative sample of 75 fruits is used as a basis for the formulation of the predicting equation.

SUMMARY AND CONCLUSIONS

Surface areas of apples were obtained by halving the apple transversely, removing the peel in narrow strips, pinning these strips to a sheet of paper, tracing the outline of the peel strips with a sharp pencil, and measuring areas of the strips of peel with a planimeter.

The peel may be lifted from the cavity and basin of an apple to form an object similar to an ellipsoid, and a formula for calculating the surface area of an ellipsoid was found to give a standard error of estimate of 0.35 square inch when employed to predict surface areas of Jonathan apples.

Linear relations, predicting equations, and standard errors of estimate were determined for planimeter surface areas of apples and each of the following measurements: Areas of transverse cross sections, areas of axial or longitudinal cross sections, transverse diameters, axial or longitudinal diameters, and weights of fruits.

The standard errors of estimate obtained by predicting surface areas from areas of transverse cross section, transverse diameter, and weights of fruits were smaller than those for other measurements tried and any one of these three measurements may be used to predict approximate surface areas. A method is presented for determining which of two such variables is the better for predicting a third variable.

The most practical predicting equation for approximate surface areas of harvested apples is based on weights of fruits, and the most suitable one for use on unpicked apples is based on transverse diameter of apples.

An average predicting equation may be used for several varieties of the same kind of fruit with standard errors of estimate nearly as low as the standard error of estimate for an equation based on a single variety.

There appears to be a rather constant relationship between surface areas and weights of apples during the several weeks prior to maturity.

Weights of pears may be used to predict surface areas of these fruits, and an average predicting equation may be used with reasonable accuracy for several pear varieties having a wide range of shapes.

Weights of plums may be used for predicting surface areas of these fruits.

EFFECT OF FERTILIZER AND ENVIRONMENT ON THE ASCORBIC ACID CONTENT OF TURNIP GREENS [1]

By RUTH REDER, *associate in agricultural chemistry research, Oklahoma Agricultural Experiment Station*, LEAH ASCHAM, formerly *home economist, Georgia Agricultural Experiment Station*, and MARY S. EHEART, *assistant professor of home economics, Virginia Polytechnic Institute* [2]

INTRODUCTION

Numerous investigations have been conducted to determine the effect of fertilizer on the ascorbic acid content of vegetables. The methods of experimentation employed have varied widely, particularly with respect to the plants studied, the cultural methods used, and the composition of the fertilizers applied. In early work ascorbic acid was determined by biological methods and in later studies by chemical methods. The lack of agreement in the results obtained in these investigations may probably be attributed, in part, to dissimilarities in the experimental procedures employed. The results indicate, in general, that the ascorbic acid content of plants tends to increase as the plant yield is increased by fertilizer application, and that nitrogen and potassium are the fertilizer constituents most effective in increasing the formation of this vitamin.

The present study represents one phase of an investigation conducted cooperatively in six States to determine the cause of variations in the composition of vegetables produced by the same cultural methods in various sections of those States. The purpose of the study, in which three of the cooperating States participated, was to determine the effect of fertilizer treatment and environmental conditions on the ascorbic acid content of turnip (*Brassica rapa* L.) greens. The experiments were conducted at Norfolk and Blacksburg, Va.; Stillwater, Okla.; and Experiment, Ga.

MATERIALS AND METHODS

Four fertilizer factors were studied. In order that not only the individual effects of the fertilizers but also the possible interrelated effects might be determined, a factorial experiment was planned. A $2\times2\times2\times2$ factorial design consisting of 16 treatments with 2 replications at each location was used. The arrangement of treatments in each replication was randomized and different arrangements were used at each location. The treatments consisted of the application of nitrogen, phosphorus, potassium, and calcium in all possible combinations of high and low levels of nutrients; the check consisted of plants produced without fertilizer treatment, i. e., the zero level of application of all four nutrients. The 16 treatments were: NPKCa,

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[2] The authors are indebted to B. L. Wade, senior geneticist in charge, U. S. Regional Vegetable Breeding Laboratory, Charleston, S. C., both for guidance in planning this project and for assistance in the statistical treatment of the data obtained in the experiments. The authors are also indebted to H. L. Cochran, associate horticulturist, Georgia Agricultural Experiment Station, R. C. Moore, assistant horticulturist, Virginia Agricultural Experiment Station, and H. H. Zimmerley, director, Virginia Truck Experiment Station, for their careful supervision of the production of the turnip greens used in these experiments.

NPK, NPCa, NP, NKCa, NK, NCa, N, PKCa, PK, PCa, P, KCa, K, Ca, and check.

Turnip seed of the Seven Top variety was supplied for the experiments by the United States Regional Vegetable Breeding Laboratory at Charleston, S. C. The seed was planted in rows 25 feet long and 30 inches apart. Each replicate consisted of 16 experimental rows with 2 border rows on each side of the area. The 2 replicates at each location were placed either side by side or end to end. Fertilizers were applied in a band 2 inches to the side of the row and 1 inch below the seed level. The fertilizers were applied at the following levels: 60 pounds per acre of nitrogen from ammonium sulphate, 60 pounds of P_2O_5 from superphosphate, 60 pounds of K_2O from muriate of potash, and 120 pounds of calcium from gypsum.

Records were kept of the maximum and minimum daily temperatures and the rainfall at each location.

Soil samples were taken after the ground was prepared for planting and before the fertilizers were applied. The samples were obtained in the following manner: A hole approximately 6 inches deep with a vertical side was dug with a garden trowel, and from the vertical side of the hole a thin, uniform slice of soil was taken from the surface to a depth of 6 inches. This operation was repeated 20 times in 2 diagonals across the field. The samples were thoroughly mixed and from the composite a sample was taken for analysis.

The pH values of the soils were determined by the use of glass electrodes. Rapid soil-test determinations for calcium, magnesium, nitrate nitrogen, and phosphorus were made by the perchlorate method of extraction devised by Dr. I. E. Miles[3]. Soil organic matter was determined by the method originally developed (*26*)[4] and later modified (*27*) by Schollenberger. Total exchange capacity and exchangeable calcium were determined by the methods of the Association of Official Agricultural Chemists (*1*).

When the first experiment was conducted at Norfolk, six samples of greens were analyzed from each experimental row. An examinaton of the results of this experiment by Immer's method (*12*) showed that there was need for a reduction in sampling error. This was achieved by increasing the number of samples to eight in the three experiments carried out in 1940. At Norfolk, Blacksburg, and Stillwater all rows of a single replicate and, in most cases, all rows of both replicates were sampled at the same time. At Experiment two collections of four samples were made on 2 different days after plants reached the proper size.

In view of the fact that the ascorbic acid content of plants varies thoroughout the day, samples were taken in the morning in each of the experiments, and all samples from a given location were collected at approximately the same time. At Norfolk and Blacksburg samples were taken from 8 to 8:30 a. m.; at Stillwater, from 7 to 7:30 a. m.; and at Experiment, at 7:30 and 9:30 a. m.

In sampling, large, medium, and small leaves were selected at random from average-sized plants. When the field was close to the laboratory, the samples were placed in a refrigerator within a few minutes after they were collected. At Stillwater, where the field was located some distance from the laboratory, the samples were

[3] Unpublished method.
[4] Italic numbers in parentheses refer to Literature Cited, p. 386.

placed in paper bags and packed at once with chipped ice in an insulated container in which they were conveyed to the laboratory.

In preparation for analysis, the leaves were thoroughly washed and rinsed in distilled water. Excess water was removed by patting them either with paper towels or cheesecloth. They were then placed in containers and stored in refrigerators at 2° to 4° C. until they were analyzed. All analyses were completed the same day on which the samples were collected. Duplicate determinations were made of the ascorbic acid content of samples from each row. Representative leaves of various sizes, selected for each sample, were cut or torn into strips which were well mixed. From them a 20-gm. sample was quickly weighed and placed in a glass mortar and covered with an acid mixture consisting of equal parts of 2 N H_2SO_4 and 0.25 N HPO_3.

At this point in the procedure there were some differences in the techniques employed. At Experiment, the method used for the determination of ascorbic acid was essentially that described by Bessey and King (*2*); in the other experiments, the method developed by Thornton (*29*) was used. In a comparision of the two methods, one of the investigators (M. S. Eheart), using both procedures to determine the ascorbic acid content of apples, found that the results obtained by the two methods were in close agreement. The same investigator found that the average percentage recovery of ascorbic acid from turnip greens was 96.9 percent for 25 samples.

The methods employed given briefly are as follows. At Experiment, the sample was ground under the acid mixture with 25 to 30 gm. of acid-washed sand, then transferred to 50-ml. centrifuge tubes. After centrifugation, the clear, supernatant liquid was poured off and the remaining material was again ground and centrifuged. This process was repeated a third time, the extracts were combined, and the volume was made up to 250 ml. with the acid mixture. Two 10-ml. aliquots of the well-mixed solution were titrated with a standardized solution of the dye 2, 6 dichlorophenolindophenol, which was added from a microburette. The dye solution, containing 60 mg. per 100 ml., was standardized daily against a solution of ascorbic acid containing 0.1 gm. Cebione (Merck) in 250 ml. of 3 percent HPO_3. The ascorbic acid solution was titrated against a 0.01 N iodine solution which was standardized against a 0.01 N As_2O_3 solution. One milliliter of 0.01 N iodine is equivalent to 0.88 mg. of ascorbic acid.

At the other laboratories, the procedure was as follows: The sample was finely ground under the acid mixture with 5 gm. of acid-washed sand. The mixture was transferred quantitatively to a 250-ml. volumetric flask and the volume was made up to 250 ml. with the acid mixture. Two portions of the well-mixed liquid were centrifuged for 1 minute, at 1,800 r. p. m. and a 5-ml. aliquot of the supernatant liquid from each portion was placed in a 125-ml. Erlenmeyer flask and titrated with the indophenol solution which was added from a microburette.

The indophenol solution was made up in Sörensen's solution, pH 7.0; 50 mg. of dye was used in 200 ml. of solution. At Norfolk and Blacksburg, the dye was standardized by the method used at Experiment except that the iodine solution was standardized against a stand-

ard solution of sodium thiosulfate. At Stillwater, a simplified method of standardization developed by Menaker and Guerrant (*17*) was used. In this method, an excess of potassium iodide is added to a measured volume of the indophenol solution in the presence of acid and the liberated iodine is titrated with a 0.01 N sodium thiosulfate solution, 1 ml. of which is equivalent to 0.88 mg. of pure ascorbic acid.

Analysis of variance of the data from each experiment was made in the usual manner. The effect of each fertilizer treatment was

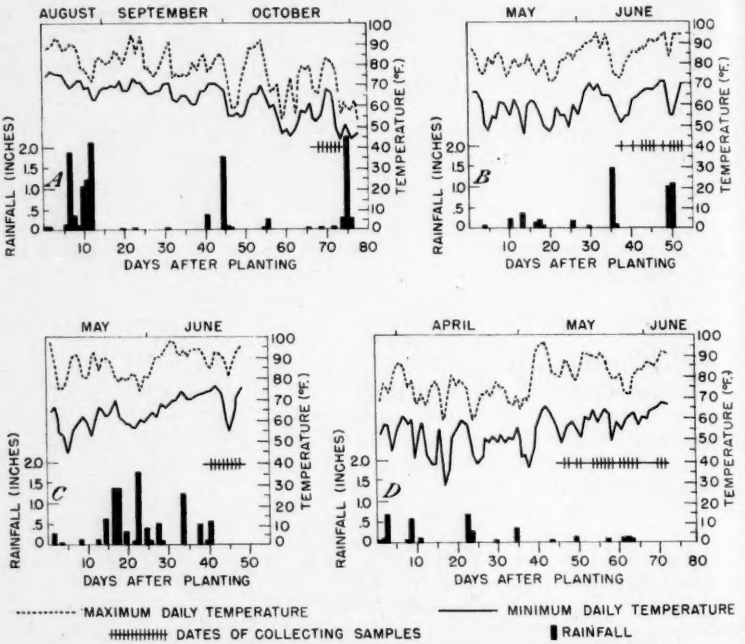

FIGURE 1.—Maximum and minimum daily temperatures, distribution of rainfall, and dates of planting and collecting turnip greens of the Seven Top variety for ascorbic acid determinations at Norfolk, Va., 1939 (*A*); Stillwater, Okla., 1940 (*B*); Blacksburg, Va., 1940 (*C*) and Experiment, Ga., 1940 (*D*).

determined by the method devised by Yates (*34*) for the analysis of factorial experiments. Chi-square tests showed the four experiments sufficiently homogeneous in error variances for satisfactory combination.

EXPERIMENTAL RESULTS

Data pertaining to the type and composition of the soil and meteorological conditions at each location during the growing season are presented in table 1. The dates of planting and collecting samples for analysis, maximum and minimum daily temperatures, and the distribution of rainfall during the growing season are shown graphically for each location in figure 1.

The average maximum temperatures at the four locations (table 1) ranged from 77.7° F. at Norfolk and Blacksburg to 83.7° at Still-

water, and the average minimum temperatures ranged from 54.2° at Blacksburg to 62.9° at Norfolk. Differences between the maximum and minimum daily temperatures (fig. 1) were smaller at Norfolk than at the other locations. The average daily rainfall (table 1) ranged from 0.06 inch at Experiment to 0.21 inch at Blacksburg. Distribution of rainfall (fig. 1) during the growing season varied considerably at the different locations. At Norfolk, 7.2 inches of rain fell during the first 13 days of the first one-third of the growing season; 2.43 inches in the second one-third; and 4.33 inches in the final period. The rains at Blacksburg were well scattered throughout the season, but the precipitation was highest during the second one-third of the period, when 6.17 inches of rain fell. At Stillwater, the rainfall was 1.26, 0.54, and 3.61 inches for the first, second, and final periods of the growing season, respectively. At Experiment, the rainfall was light and most of it fell during the first one-third of the season.

The results obtained in the 4 experiments are given in table 2, both separately and in combination. In each experiment, the average value given for the ascorbic acid content of greens receiving a given treatment is an average of the values obtained for all samples which received this treatment in the 2 replicates; in the experiment at Norfolk, this value is an average of the ascorbic acid content of 12 samples, 6 samples having been taken from a given treatment in each replicate; in the other 3 experiments, the value is an average of 16 samples.

TABLE 1.—*Type and composition of soils on which turnip greens (Seven Top) were produced, and meteorological data recorded during the growing season, at Norfolk and Blacksburg, Va.; Stillwater, Okla.; and Experiment, Ga.*

Location of experiment	Elevation	Soil type	Soil reaction	Composition of soil [1]							Meteorological data for growing period							
				Ca	Mg	N (nitrate)	P	Organic matter	Total exchange capacity [2]	Exchangeable Ca [2]	Rainfall		Average temperature		Days—			
											Total	Average daily	Maximum	Minimum	With rainfall over 0.01 inch	Clear	Partly cloudy	Cloudy
	Feet		*pH*					*Per cent*	*Milligrams*	*Milligrams*	*Inches*	*Inches*	*°F.*	*°F.*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Norfolk, Va.	11	Norfolk sandy loam	5.8	L− [1]	L	M−	L+	2.47	7.6	2.3	13.08	0.17	77.7	62.9	27	32	33	35
Blacksburg, Va.	2,170	Dunmore silt loam	5.5	T+	L−	M−	L	2.42	7.2	1.6	10.2	.21	77.7	54.2	52	27	29	44
Stillwater, Okla.	880	Canadian loamy fine sand	6.0	H	M+	L+	L−	1.35	5.5	2.8	5.44	.10	83.7	59.6	25	50	29	21
Experiment, Ga.	946	Cecil sandy clay loam	5.7	L	L−	M−	L+	1.62	6.3	3.8	4.01	.06	78.8	54.4	26	49	17	34

[1] Pounds per acre for letters used in recording the results of the buffered perchloric acid test.

Elements estimated	Trace (T)	Low (L)	Medium (M)	High (H)	Very high (VH)
Calcium	0–300	−1,000	−2,000	−3,000	−4,000
Magnesium	0–10	−30	−90	−150	−200
Nitrogen (nitrate)	0–5	−20	−50	−70	−100
Phosphorus	0–10	−50	−100	−250	−400

[2] Milligrams per 100 gm. of soil.

TABLE 2.—*The ascorbic acid content of turnip greens (Seven Top) grown in factorial design of 16 duplicate fertilizer treatments at 4 locations, and the effects [1] of the treatments at each location and for the 4 locations combined*

Fertilizer treatment	Plants grown at—									
	Norfolk, Va.		Blacksburg, Va.		Stillwater, Okla.		Experiment, Ga.		All locations	
	Ascorbic acid content [2]	Effect [3] of treatment	Ascorbic acid content	Effect of treatment	Ascorbic acid content	Effect of treatment	Ascorbic acid content	Effect of treatment	Ascorbic acid content [4]	Effect [5] of treatment
	Mg. per gm.	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*	*Mg. per gm.*
NPKCa	2.2991	−0.0583	1.4062	−0.0093	1.4826	−0.0022	1.6194	−0.0105	1.6620	−0.0175
NPK	2.4723	−.0142	1.4013	+.0233	1.4938	−.0080	1.7769	+.0665	1.7403	+.0190
NPCa	2.3724	−.0569	1.3610	−.0126	1.5588	−.0034	1.9438	+.0634	1.7714	+.0013
NP	2.3528	−.0127	1.3934	+.0759**	1.5829	+.0017	1.8325	−.0577	1.7529	+.0020††
NKCa	2.5716	+.0268	1.2267	+.0006	1.5031	+.0166	1.7444	−.0626	1.7074	−.0067
NK	2.4281	+.0659	1.2232	+.0351	1.5468	−.0003	1.8506	−.0102	1.7178	+.0198
NCa	2.3683	−.0780*	1.2911	−.0062	1.5148	−.0257	2.0319	−.0362	1.7638	−.0337*
N	2.4873	+.0174	1.2761	+.0762**	1.5677	−.0944**	1.9950	−.1145*	1.7878	−.0292*††
PKCa	2.4129	−.0555	1.2230	+.0215	1.5982	+.0032	1.7813	−.0209	1.7099	−.0101
PK	2.2535	−.0103	1.1633	+.0193	1.5799	−.0252	1.8469	−.0535	1.6747	−.0179
PCa	2.5268	+.0124	1.2773	+.0011	1.6868	+.0187	2.0719	−.0576	1.8483	−.0076
P	2.3004	−.0730	1.2895	+.0603**	1.6239	−.0053	2.1613	−.0546	1.8133	−.0147††
KCa	2.3933	−.0094	1.1983	+.0058	1.5949	−.0111	2.0294	−.0404	1.7647	−.0141
K	2.3780	−.0183	1.2272	−.0512*	1.6316	−.0493*	1.8325	−.1927**	1.7266	−.0819**††
Ca	2.5206	+.0457	1.3061	+.0039	1.6598	−.0072	2.0594	+.0073	1.8442	+.0102
Check	2.4271		1.2842		1.6303		1.9275		1.7766	
Mean	2.4103		1.2842		1.5785		1.9065		1.7539	
Standard deviation	.2476		.1495		.1431		.3091		.2234	
Significant difference in average effects at the 5 percent level		.0762		.0398		.0381		.1054		.0288
Significant difference in average effects at the 1 percent level		.1053		.0551		.0527		.1458		.0384

F values for variance analysis at the 4 locations combined are: Places = 1,022.27**; treatments = 3.513**; treatment × places = 2.687**.

* Significant at the 1-percent level.

** Significant at the 5-percent level.

†† Interaction of treatment × places is significant at the 1-percent level.

[1] All data were used in calculating the effect of each fertilizer treatment. For example, the effect of nitrogen on the ascorbic acid content of plants grown at a given location was calculated in the following manner: After adding the replicates together to get a total for each of the 16 treatments the 8 containing nitrogen, i. e., N, NCa, NK, NKCa, NP, NPCa, NPK, and NPKCa, were added together and the 8 not containing nitrogen were added together. The difference between the positive combinations and the negative combinations is the total algebraic effect of nitrogen. (See table 3.) The effect of each of the single fertilizers at a given location was calculated in a similar manner. For the calculation of the effects of treatments containing two or more fertilizer constituents consult table 3 or Yates (*54*).

[2] Each value is an average of 16 samples from duplicate plots at all locations except at Norfolk, where the value is an average of 12 samples

[3] Each value is an average of 128 samples from 16 plots at all locations except at Norfolk, where the value is an average of 96 samples.

[4] Each value is an average of 60 samples from 8 plots.

[5] Each value is an average of 480 samples from 64 plots.

The average effect of each fertilizer treatment was calculated for each experiment and these effects are shown in table 2. The method of calculation is shown in table 3. In all cases these effects make use of more of the data than do the averages compiled from the treatment alone; for example, in each experiment only 2 rows received nitrogen, but the effect of nitrogen in the experiment is calculated on the basis of 16 rows, since half of the 32 rows in the 2 replicates received nitrogen and half did not. At Norfolk, each effect was calculated from the ascorbic acid content of 96 samples; at the other locations, from the results of the analyses of 128 samples. The significance of these results was determined and significant effects are designated in the table.

As may be seen from an inspection of table 2, five of the fertilizer treatments gave significant effects at one or more places; these were the simple fertilizers, N, P, and K and the combinations NP and NCa. The largest number of significant effects in one experiment was observed at Blacksburg, where four treatments significantly affected the ascorbic acid content of the greens. Two treatments gave significant effects at Experiment, two at Stillwater, and one at Norfolk.

Treatment with nitrogen fertilizer gave the most interesting results; at Blacksburg and Norfolk, nitrogen produced an increase in ascorbic acid content (significant at Blacksburg), but at Stillwater and Experiment, the application of nitrogen resulted in significant decreases in this vitamin. The decrease was significant for the combination of the four places, and the interaction of N treatment × places was highly significant.

TABLE 3.—*Main effects and ineractions in a 4-factor experiment*

	Combination of treatments																													
	Check		Ca	K	KCa	P	PCa	PK	PKCa	N	NCa	NK	NKCa	NP	NPCa	NPK	NPKCa													
Total	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+													
ca	−		+	−	+	−	+	−	+	−	+	−	+	−	+	−	+													
k	−		−	+	+	−	−	+	+	−	−	+	+	−	−	+	+													
kca	+		−	−	+	+	−	−	+	+	−	−	+	+	−	−	+													
p	−		−	−	−	+	+	+	+	−	−	−	−	+	+	+	+													
pca	+		−	+	−	−	+	−	+	+	−	+	−	−	+	−	+													
pk	+		+	−	−	−	−	+	+	+	+	−	−	−	−	+	+													
pkca	−		+	+	−	+	−	−	+	−	+	+	−	+	−	−	+													
n	−		−	−	−	−	−	−	−	+	+	+	+	+	+	+	+													
nca	+		−	+	−	+	−	+	−	−	+	−	+	−	+	−	+													
nk	+		+	−	−	+	+	−	−	−	−	+	+	−	−	+	+													
nkca	−		+	+	−	−	+	+	−	+	−	−	+	+	−	−	+													
np	+		+	+	+	−	−	−	−	−	−	−	−	+	+	+	+													
npca	−		+	−	+	+	−	+	−	+	−	+	−	−	+	−	+													
npk	−		−	+	+	+	+	−	−	+	+	−	−	−	−	+	+													
npkaca	+		−	−	+	−	+	+	−	−	+	+	−	+	−	−	+													

The effect of potassium in the fertilizer was to decrease the ascorbic acid in each of the four experiments. This decrease was significant in three places and for the combination of all places. The average decrease effected in ascorbic acid content was 8.2 mg. per 100 gm. of fresh material for 480 samples which were treated with fertilizer containing potassium, as contrasted with the same number of samples not fertilized with potassium. There was also a significant interaction between places and the treatment effect of potassium; this indicates that there was a much greater decrease due to potassium applications at Experiment than at any of the other three places.

Phosphorus gave a significant effect only at Blacksburg, where it increased the ascorbic acid content. At the other three places the effects were negative but not significantly so. The effect for P treatment × places was highly significant. Calcium was associated with an increase in ascorbic acid content in three places and with a decrease in one place, but none of the effects were significant. The interaction of Ca treatment × places was not significant.

The combination of NP gave a highly significant increase at Blacksburg, a nonsignificant increase at Stillwater, and nonsignificant decreases at the other two places. The interaction of NP treatment × places was highly significant. The combination of NK gave nonsignificant increases at two places and nonsignificant decreases at two places. The effect for the combination of four places was not significant. NCa gave decreases at four places, significant at one place, and the decrease for the combination of four places was significant.

The most striking observation to be made from the four experiments is that at Norfolk, where the maximum vitamin formation was obtained, the mean ascorbic acid content of the greens (2.4103 mg. per gm.) was nearly twice as great as that of greens grown at Blacksburg, where the mean ascorbic acid content (1.2842 mg. per gm.) was the lowest observed in the experiments. The mean ascorbic acid content of the greens produced at Experiment and Stillwater was 1.9065 and 1.5785 mg. per gm., respectively. The influence of places was 13.75 times as great as the most important average effect, i. e., the effect for potassium, but when compared to the effect of potassium at Experiment, place difference was only five times as great.

DISCUSSION

Several earlier investigators (*16*, *21*, *23*, *24*, *25*, *32*, *33*) found no changes in the ascorbic acid content of various plants as a result of fertilizer treatment. A few workers have reported that certain fertilizer ingredients altered the ascorbic acid content of some plants. None of these investigators, however, worked with turnip greens. The significant decreases in ascorbic acid produced by nitrogen in the fertilizer at two places and the significant decrease obtained by combining the results from all four places are directly opposed to the findings of a number of other workers who found nitrogen to increase the ascorbic acid content of many plants (*3*, *6*, *10*, *11*, *13*, *19*). The highly significant interaction of N treatment × places in the present experiments suggests one reason for the lack of agreement; i. e., the effect of place is more important than the effect of fertilizer.

The most consistent effect obtained in the four experiments was the decrease in the ascorbic acid content of greens which received potassium fertilizer. The opposite effect was observed by Hester (*7*), Ijdo (*10*), and others (*11*, *22*); Isgur and Fellers (*13*) and Fellers et al. (*4*) found no change in the ascorbic acid of plants as a result of potassium fertilization.

The highly significant interaction of potassium effect × places, although all places showed a decrease in ascorbic acid content, indicates that potassium reduced the ascorbic acid content more sharply in one location than in another. The greatest reduction was found at Experiment, Ga.

The effect of phosphorus in the fertilizer was not significant for the combination of the four places. This confirms the results of previous studies (*10*, *13*) with spinach and Swiss chard. Ott (*19*), however, increased the amount of this vitamin in potatoes by applying nitrogen and phosphorus, and Pfützer and Pfaff (*22*) increased it in vegetables by the addition of phosphate to a phosphorus-deficient soil. The ineffectiveness of calcium in the fertilizer in significantly modifying the ascorbic acid content of the greens in the present experiments confirms the results obtained by Ijdo (*10*) with spinach.

NCa was the only fertilizer combination to give an effect significant for the combination of the four places. Several investigators (*3*, *5*, *9*, *28*, *31*) have found that the ascorbic acid of different vegetables was increased by the application of the fertilizer combinations NPK or NPKCa, but the effects of these combinations in the present experiments were not significant. Ott (*20*) found that tomatoes grown without fertilization contained more vitamin C than those fertilized with NPK.

The results show that under the conditions imposed in these experiments, fertilizer treatment significantly affected the ascorbic acid content of turnip greens, but that the effect of place was more important than the greatest effect obtained with any fertilizer. Factors contributing to the effect of place are the type and composition of the soil and meteorological conditions during the growing season. Different types of soil were used at the four locations (table 1), but the results of the soil analyses (table 1) do not reveal very marked differences in soil composition. It is possible that trace elements in the soil exert an effect on ascorbic acid formation; Hester (*8*), for example, indicated that the amount of manganese in the soil is an important factor affecting the ascorbic acid content of plants. From the results obtained, no conclusions may be drawn as to the relationship between either soil composition or temperature and the ascorbic acid content of turnip greens.

The fact that the greens which had the highest ascorbic acid content were grown in the fall suggests a seasonal variation in the ascorbic acid content of turnip greens. No conclusion may be drawn from this fact, but the observation is made in view of the results obtained by Tressler, Mack, and King (*30*), who found that spinach produced at two locations in the fall contained one-third more ascorbic acid than spinach grown in the spring at the same locations. Because of the seasonal effect observed by these investigators, the three spring crops are compared; of these, the crop having the highest ascorbic acid content (1.9065 mg. per gm.) was grown at Experiment, where the average daily rainfall was lower than at any of the other three places, and 49 percent of the days were clear. At Blacksburg, where the greens had the lowest average ascorbic acid content (1.2842 mg. per gm.), the average daily rainfall was greatest and only 27 percent of the days of the growing season were clear. These results indicate an inverse relationship between the amount of rainfall and ascorbic acid content of the greens and a direct relationship between the amount of sunshine and the formation of ascorbic acid. Several investigators (*14*, *15*, *18*) have shown that the ascorbic acid content of plants is directly influenced by light intensity. Experiments are in progress to investigate further the effect of season and other environmental factors on the ascorbic acid content of turnip greens.

SUMMARY AND CONCLUSIONS

Experiments were conducted at Norfolk and Blacksburg, Va., Stillwater, Okla., and Experiment, Ga., to determine the effects of fertilizer treatment and environmental conditions on the ascorbic acid content of turnip greens. A factorial design was used for applications of N, P, K, and Ca in all possible combinations at a high and low level for each nutrient.

Uniform methods of planting and fertilizing were used with seed of the variety Seven Top from a single source. Meteorological data were recorded for each experiment and soil samples from each area were analyzed for calcium, magnesium, nitrate nitrogen, phosphorus, organic matter, total exchange capacity, exchangeable calcium, and pH values. Chemical methods were used for the determination of ascorbic acid. The results of the experiments were analyzed statistically, both separately and in combination, and are discussed in terms of the calculated effects of the fertilizer treatments.

Three of the single fertilizer treatments, N, P, and K, and two of the fertilizer combinations gave significant effects at one or more places. Nitrogen fertilizer gave increases in ascorbic acid at two places (significant at one place) and significant decreases at two places. The decrease for the four places combined was significant. The interaction of N treatment $\times$ places was highly significant.

The most consistent results were obtained with potassium fertilizer, which produced a decrease in ascorbic acid in each experiment; the decreases were significant at three places and highly significant for the combination of places. Many investigators working with other plants have found the application of potassium fertilizers to increase the ascorbic acid content.

Phosphorus gave a significant increase at one place and nonsignificant decreases at three places. The effect for P treatment $\times$ places was highly significant. Calcium produced no significant effects and the interaction of Ca treatment $\times$ places was not significant.

The combination of NP gave a highly significant increase at one place and the interaction of NP treatment $\times$ places was highly significant. NK gave nonsignificant increases at two places, and nonsignificant decreases at two places. The effect was not significant for the combination of places. NCa gave decreases at all places, significant at one place, and the decrease was significant for the combination of four places.

Wide variations were obtained in the ascorbic acid content of greens produced at the four places; the mean ascorbic acid content of greens at Norfolk (2.4103 mg. per gm.) was nearly twice that of greens at Blacksburg (1.2842 mg. per gm.). In the four experiments, the influence of place was 13.75 times as great as the most important average effect produced by fertilizer treatment. These variations did not appear to be directly related to differences in soil composition or to differences in temperature. Fertilizers represent at most only a small part of the total environment of a plant; consequently it could not be expected that controlled applications of fertilizer would have as much effect as the total environment involving differences in soil and weather.

Influence of season is suggested by the fact that the one fall crop had the highest ascorbic acid content, but this result is confounded

with the effect of place so that no definite conclusion may be reached. The highest ascorbic acid content of the three spring crops (1.9065 mg. per gm.) was found in greens which were produced at the place having the lowest average daily rainfall and where 49 percent of the days in the growing season were clear; the lowest ascorbic acid content (1.2842 mg. per gm.), was found in greens which received the greatest average daily rainfall and the least amount of sunshine. These results seem to indicate that the formation of ascorbic acid may be influenced by light intensity and rainfall as well as by fertilizer applications.

LITERATURE CITED

(1) Association of Official Agricultural Chemists.
1940. official and tentative methods of analysis . . . Ed. 5, 757 pp., illus. Washington, D. C.

(2) Bessey, O. A., and King, C. G.
1933. the distribution of vitamin c in plant and animal tissues, and its determination. Jour. Biol. Chem. 103: 687–698.

(3) Burrell, R. C., Brown, H. D., and Ebright, V. R.
1940. ascorbic acid content of cabbage as influenced by variety, season, and soil fertility. Food Res. 5: 247–252.

(4) Fellers, C. R., Young, R. E., Isham, P. D., and Clague, J. A.
1934. effect of fertilization, freezing, cooking and canning on the vitamin c and a content of asparagus. Amer. Soc. Hort. Sci. Proc. (sup. v., 1934) 31: 145–151, illus.

(5) Hahn, F.-V., and Görbing, J.
1933. vitaminstudien. sechste reihe. einfluss der düngung auf den c-vitamingehalt von spinat. Ztschr. f. Untersuch. der Lebensmitl. 65: [601]–616, illus.

(6) Hausen, S. von.
1933. zur kenntnis der vitaminbildung in pflanzen. [vitamin formation in plants.] Acta Chem. Fennica (B) 6: 62. (Abstract in Chem. Abs. 28: 2388. 1934.)

(7) Hester, J. B.
1940. the influence of potash upon the yield and quality of tomatoes. Amer. Fert. 93 (11): [5]–8, 24, 26, illus.

(8) ———
1941. manganese and vitamin c. Science 93: 401.

(9) Hoffman, I. C., Krauss, W. E., and Washburn, R. G.
1938. the effect of some varietal, cultural, harvesting, and storage conditions upon the content of certain mineral salts and vitamins in tomato fruits. Ohio Agr. Expt. Sta. Ann. Rpt. 56 (Bul. 592): 66–67.

(10) Ijdo, J. B. H.
1936. the influence of fertilizers on the carotene and vitamin c content of plants. Biochem. Jour. 30: 2307–2312.

(11) Illʹūviev, V. P. [Illyuviev, V. P.], and Ulanova, M. N.
1937. vitamin c content in berries and vegetables depending on variety and cultivation. Bul. Appl. Bot., Genet., and Plant Breeding, Sup. 84, Vitamin Prob. 2: 95–107. [In Russian. English summary, p. 5, summaries section.] (Abstract in Chem. Abs. 33: 1405. 1939.)

(12) Immer, F. R.
1932. a study of sampling technic with sugar beets. Jour. Agr. Res. 44: 633–647.

(13) Isgur, B., and Fellers, C. R.
1937. a preliminary study of the relationship between vitamin c content and increased growth resulting from fertilizer applications. Amer. Soc. Agron. Jour. 29: 890–893.

(14) Kohman, E. F., and Porter, D. R.
1940. solar rays and vitamin c. Science 92: 561.

(15) McIntosh, J.
1938. SOME FACTORS AFFECTING THE VITAMIN C CONTENT OF TOMATOES AND RUTABAGAS. Maine Agr. Expt. Sta. Ann. Rpt. 1937–38. (Bul. 391): 320–321.
(16) Mack, G. L., Tapley, W. T., and King, C. G.
1939. VITAMIN C IN VEGETABLES. X. SNAP BEANS. Food Res. 4: 309–316.
(17) Menaker, M. H., and Guerrant, N. B.
1938. STANDARDIZATION OF 2,6-DICHLOROPHENOLINDOPHENOL: AN IMPROVED METHOD. Indus. and Engin. Chem., Analyt. Ed., 10: 25–26, illus.
(18) Mituda, H.
1938. STUDIES ON VITAMIN C. 2. ON THE VARIATIONS OF THE VITAMIN C CONTENT IN SOME FRUITS. Agr. Chem. Soc. Japan Jour. 14: 1335–1340, illus. (Abstract in Nutr. Abs. and Rev. 8: 973. 1939.)
(19) Ott, M.
1937. ÜBER DEN GEHALT VON FELD- UND GARTENFRÜCHTEN AN VITAMIN C UND CAROTIN BEI VERSCHIEDENER DÜNGUNG. Angew. Chem. 50: 75–77, illus. (Abstract in Nutr. Abs. and Rev. 7: 45. 1937.)
(20) ———
1938. PFLANZENQUALITÄT, VOLKSERNÄHRUNG UND DÜNGUNG. Forschungsdienst 5: 546–552, illus. (Abstract in Nutr. Abs. and Rev. 8: 401. 1938.)
(21) Pfaff, C., and Pfützer, G.
1937. ÜBER DEN EINFLUSS DER ERNÄHRUNG AUF DEN CAROTIN- UND ASCORBINSÄUREGEHALT VERSCHIEDENER GEMÜSE- UND FUTTERPFLANZEN. Angew. Chem. 50: 179–184. (Abstract in Chem. Abs. 31: 3620. 1937.)
(22) Pfützer, G., and Pfaff, C.
1938. ZUSAMMENHÄNGE ZWISCHEN MINERALSTOFFAUFNAHME UND VITAMINGEHALTEN VON PFLANZEN [INTERDEPENDENCE OF MINERAL UPTAKE AND VITAMIN CONTENT OF PLANTS.] Fortschr. der Landw.- Chem. Forsch. 1937: 104–115, illus. (Abstract in Chem. Abs. 33: 3954. 1939.)
(23) Scheunert, A.
1938. ÜBER ERNÄHRUNGSVERSUCHE MIT VERSCHIEDEN GEDÜNGTEN GEMÜSEN. ÜBER DEN VITAMINGEHALT VON GEMÜSEN, WELCHE EINERSEITS MIT STALLDUNG, ANDERSEITS MIT STALLDUNG + NPK GEDÜNGT WURDEN. [NUTRITION INVESTIGATIONS WITH VARIOUS FERTILIZED VEGETABLES. THE VITAMIN CONTENT OF VEGETABLES FERTILIZED WITH MANURE AND WITH MANURE PLUS N, P AND K MIXTURE.] Ernährung 3: 67–69. (Abstract in Chem. Abs. 32: 3846. 1938.)
(24) ——— Reschke, J.
1938. ÜBER DEN VITAMIN C-GEHALT VON GEMÜSEN, WELCHE EINERSEITS MIT STALLDUNG, ANDERERSEITS MIT STALLDUNG + NPK GEDÜNGT WORDEN WAREN. Forschungsdienst 6: 34–48.
(25) ——— Reschke, J., and Kohlemann, E.
1940. ÜBER DEN VITAMIN C-GEHALT DER KARTOFFELN. IV. MITTEILUNG: ÜBER DEN EINFLUSS VERSCHIEDENER DÜNGUNG. Biochem. Ztschr. 305: 1–3.
(26) Schollenberger, C. J.
1927. A RAPID APPROXIMATE METHOD FOR DETERMINING SOIL ORGANIC MATTER. Soil Sci. 24: 65–68, illus.
(27) ———
1931. DETERMINATION OF SOIL ORGANIC MATTER. Soil Sci. 31: 483–486.
(28) Sugawara, T.
1938. INFLUENCE OF FERTILIZERS ON THE ASCORBIC ACID (VITAMIN C) CONTENT OF SPINACH. Jour. Sci. Soil and Manure, Japan 12: 567–576. (Abstract in Chem. Abs. 33: 1077. 1939.)
(29) Thornton, N. C.
1938. EXTRACTION AND DETERMINATION OF VITAMIN C IN PLANT TISSUE. Boyce Thompson Inst. Contrib. 9: 273–281.
(30) Tressler, D. K., Mack, G. L., and King, C. G.
1936. VITAMIN C CONTENT OF VEGETABLES. I. SPINACH. Food Res. 1: 3–7.

(31) VOGEL, F.
1939. ERGEBNISSE DER ZWEIJÄHRIGEN GEMEINSCHAFTSARBEITEN ÜBER DEN EINFLUSS DER DÜNGUNG AUF ERTRAG UND GÜTE VON WEISSKOHL. Bodenk. u. Pflanzenernähr. 15: 134–139.
(32) WACHHOLDER, K., and NEHRING, K.
1938. ÜBER DEN VITAMIN C-GEHALT VERSCHIEDENER KARTOFFELSORTEN UND SEINE ABHÄNGIGKEIT VON DER DÜNGUNG. Bodenk. u. Pflanzenernähr. (n. s.) 9–10: 708–724, illus.
(33) WENDT, H., PIES, [R.], PRÜFER, J., and others.
1938. ÜBER ERNÄHRUNGSVERSUCHE MIT VERSCHIEDEN GEDÜNGTEN GEMÜSEN. Ernahrung 3: [53]–69.
(34) YATES, F.
1937. THE DESIGN AND ANALYSIS OF FACTORIAL EXPERIMENTS. Imp. Bur. Soil Sci. Tech. Commun. 35, 95 pp.

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